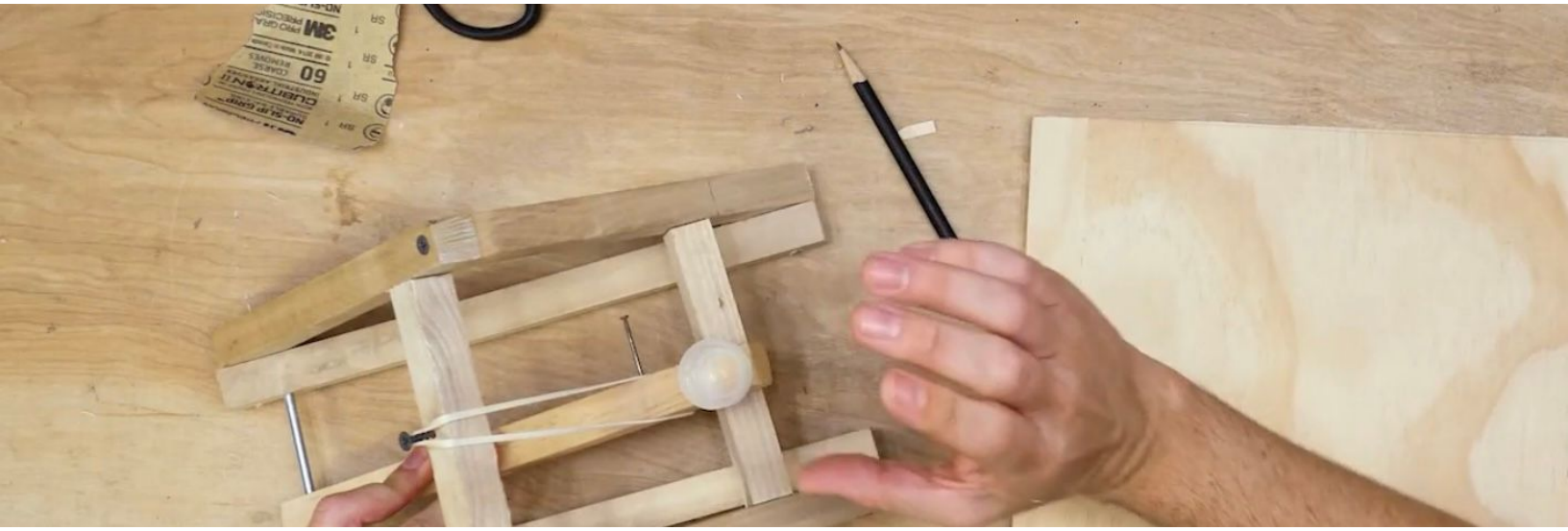


Mark's Catapult Build

Introduction

Here are some step-by-step instructions that walk through the build process for the catapult that Mark makes in his prototyping lesson. If you're looking for a simpler project, or one that does not require power tools, see the Simple Catapult for Beginners guide.

This is a completely optional resource — NOT a homework assignment! If you're incorporating a catapult into your build and want to start with something similar to Mark's prototype, this may help you fill in the gaps in Mark's build process.

Remember, Mark figured out how he wanted to assemble this build as he was doing it in the prototyping phase, so it wasn't planned out perfectly ahead of time. So, you'll see him do things in the video lesson like add a piece and then decide to remove it later on. We've flagged those moments in this document so you can avoid unnecessary work, but you may need to be a bit flexible.

Materials

- 3/4"x3/4" square wooden dowels
  - You'll need enough length to cut:
    - 2x 5" pieces
    - 2x 7" pieces
    - 2x 7-3/4" pieces
    - 2x 11" pieces
    - 1x 10" piece
  - You should be able to do this with 3x 36" long dowels, but you may want to buy a few extra dowels in case you need to remake a piece.
- 15-20x drywall screws, at least 1" long
- 1/8" circular metal rod, at least 5" long
  - You can also use a circular wooden dowel, but metal is preferred.
- Rubber band
- Bottle cap

Tools

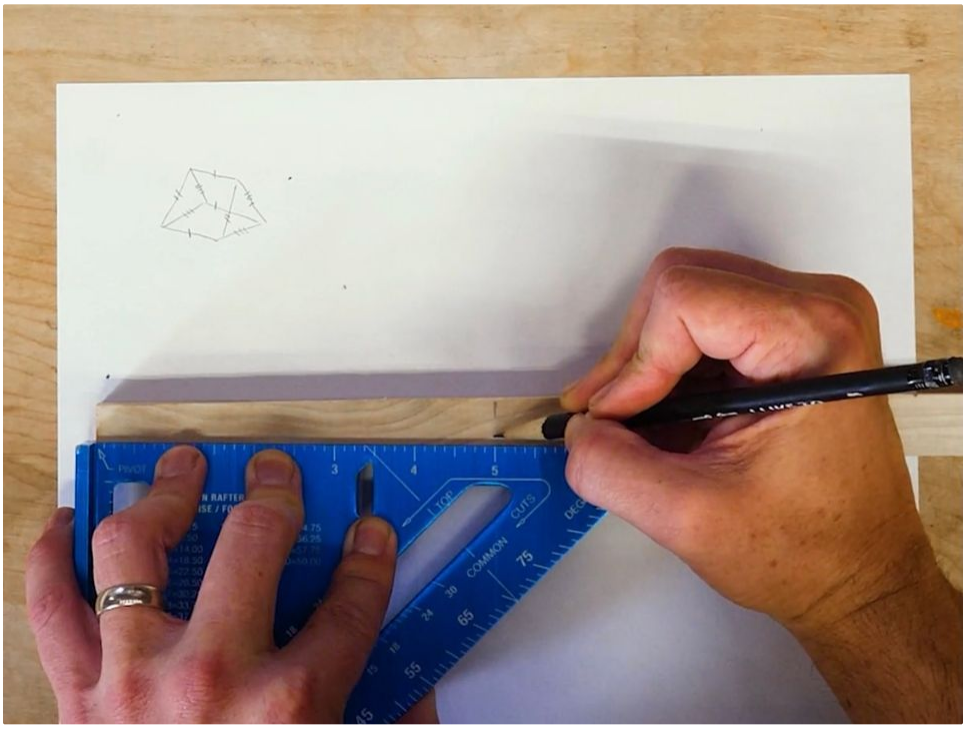
- Pencil
- Ruler or set square
- Hacksaw with blades that can cut wood and steel
- Clamps, a bench vise, or a miter box

- Power drill/driver, with:
  - A small drill bit that matches the inner diameter of your screws for drilling pilot holes
    - If you bought #6 screws, like those listed above, you'll need a 3/32″ or 9/64″ drill bit.
  - 1/8″ drill bit for drilling your axle holes
  - A screwdriver bit to match your screws
  - You can also use a separate drill and impact driver instead of a single drill/driver, which is what Mark does.
- Sandpaper with a grit count higher than 220, for deburring the metal axle.
- Eye protection
- Ear protection
- Optional: A drill stop that corresponds to the length of screw you are planning to use.

Assembling the Catapult

Preparing the Dowel Pieces

(1) Use your ruler or set square to measure 5″ from the edge of one of your square wooden dowels. Mark your measurement with a pencil.



(2) Secure your dowel for sawing using a clamp, vise, or miter box. Then, use a hacksaw to cut your dowel at the 5″ mark.

- Start slowly, right at your pencil mark, and use short strokes until you establish a groove in the wood. Then, continue sawing with strong, slow strokes directed away from you, using the groove as a guide to help you make a straight and even cut.

▶ Safety tips on using a hacksaw

(3) Then, cut 1 additional 5″ pieces. You can measure the markings for the second off of your first piece to ensure that both are the same length.

- *NOTE*: Mark cuts 3 total 5″ pieces, but he ends up removing the third later in the build process, so you don't need the third piece.

(4) Next, measure and cut 2x 7″-long pieces of the square dowel, and 2 additional pieces that are 7 3/4″ long.

- These 4 pieces will form the shorter legs of your catapult's triangles. The extra 3/4″ on the second pair allows you to attach the pieces to each other to form a right angle, so if you're using a dowel of a different width, you may need to adjust the length of the second pair (to 7″ + the width of your dowel).

- So, now you should have:
  - 2x 5″ pieces of dowel (Mark has 3, but he eventually removes the third)
  - 2x 7″ pieces of dowel
  - 2x 7-3/4″ pieces of dowel (or 7″ + the width of your dowel)

Building the Frame

(1) Align the square end face of one of the 7″ dowel pieces with the side edge one of the 7 3/4″ dowel pieces to form a right angle.

- The two "legs" of your angle should be the same length, since the extra length of the longer piece of dowel overlaps with the face of the shorter dowel. Repeat with the other two pieces.

(2) It's almost time to attach the pieces for form the right angle, but you first need to drill a pilot hole before using a screw. To do this, start by selecting a drill bit.

- This gets some of the material out of the way and reduces the chance of splitting or damaging the wood. Select a drill bit that is similar in diameter to the minor diameter of the screws you are going to use (the minor diameter is the diameter of the screw not including the thread)

(3) Attach the drill bit to your drill, and drill a pilot hole through the longer piece of dowel, where the two dowels meet, into the end face of the shorter dowel.

- You may want to clamp the two dowels together, and to a surface or table, especially if you are less experienced using a drill.
- Your pilot hole should be perpendicular to the edge of your longer dowel and as deep as the length of your screws. You can either eyeball the depth of your hole or use a drill stop, if you have one that matches the length of your screws. Of course, your screws need to be long enough to get all the way through the longer dowel and into the end face of the shorter one!

▶ Safety tips for using a drill/driver

(4) Then, screw one of your screws into the pilot hole.

- Mark uses a separate impact driver for this step, but you can just switch out the drill bit on your power drill / driver for a screwdriver bit and use that.

(5) Repeat steps 3 and 4 with the other set of dowels.

(6) Use the same pilot hole and screwing process to attach one of the 5″ pieces to one of your triangle legs, about 3″ from the end of the dowel. It should be perpendicular to both of the other dowel pieces.

- *NOTE:* Mark attaches two 5″ pieces in this step in the video lesson, but he removes one later on because it obstructs the catapult arm. You only need one, but if you find it easier to do the following steps with two, you can add the second one and remove it later on, as Mark does.

(7) Line up the second angle piece with the first, and align it to the exposed ends of the 5″ piece you just attached. Then, drill a pilot hole and screw the second angle piece into the 5″ dowel.

- *NOTE:* Mark has two 5″ braces when he does this step, but he ends up removing the second one later on. You only need one, but if you find it easier to do this step with two, you can add the second one and remove it later on, as Mark does.

(8) Measure the length of dowel needed for your base pieces by placing your frame upright on a surface and aligning a dowel to the two base points of on of the two right angles.

It should be approximately 11″. Then, cut two pieces of this length.

(9) Align the final 5″ dowel piece to the two right angle assemblies so that it is positioned along one dowel, just below the right angle attachment to the other dowel piece.

- You don't want the brace to be at the top of the points because it may interfere with the movement of your catapult arm. Repeat the process of drilling a pilot hole and screwing to attach the 5″ piece to the dowels on both sides.

Attaching the Axle and Catapult Arm

(1) The axle is a rotating component that allows the catapult arm to move. For this, you'll need a 1/8″ metal rod or wooden circular dowel.

Metal is preferable, since the friction between it and the wood will be lower, so the arm will rotate more easily.

(2) Select a drill bit that is the same width as your circular dowel, and use it to drill a hole through both ~11″ base dowel pieces, about 1 inch from the end.

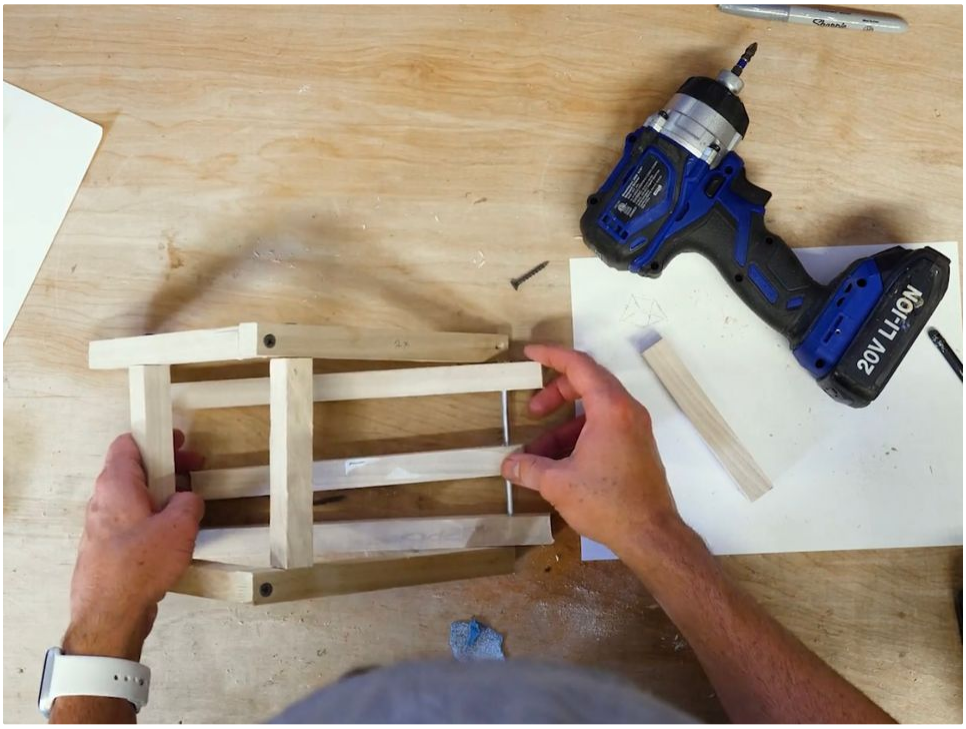
It's important that the two holes align, so you may want to clamp the dowels together and drill through both. Check to make sure the dowel fits snugly in the holes.

(3) Measure and cut a piece of circular dowel that is 5″ long.

(4) You may want to sand or de-burr the end of your dowel, especially if you're working with metal, so that you don't get scratched.

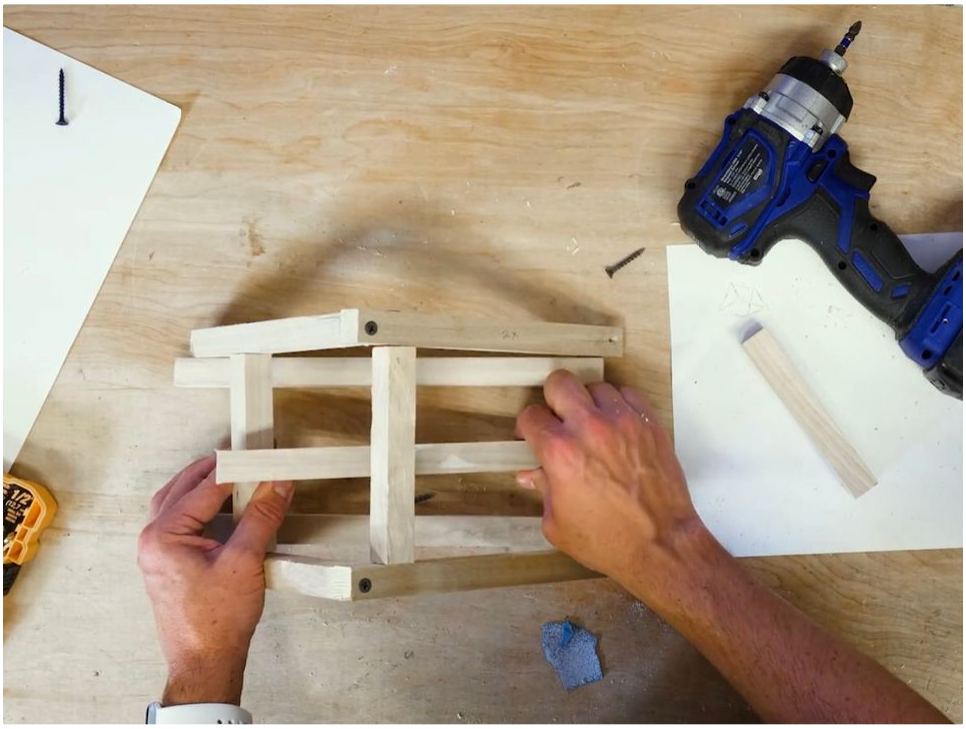
(5) Cut a piece of square dowel that is approximately 10″ long to use as your catapult arm.

Drill a hole about half an inch from the edge of the dowel piece, and then thread the 5″ circular dowel through all three square dowels with holes in them - one base piece, the catapult arm, and then the other base piece. Check to make sure the arm can rotate, and if it can’t, try widening the hole.



(6) You should now be able to test the range of motion of of the catapult arm. The axle should be on rear side of the right angle assemblies, which is the side without a low 5″ brace piece.

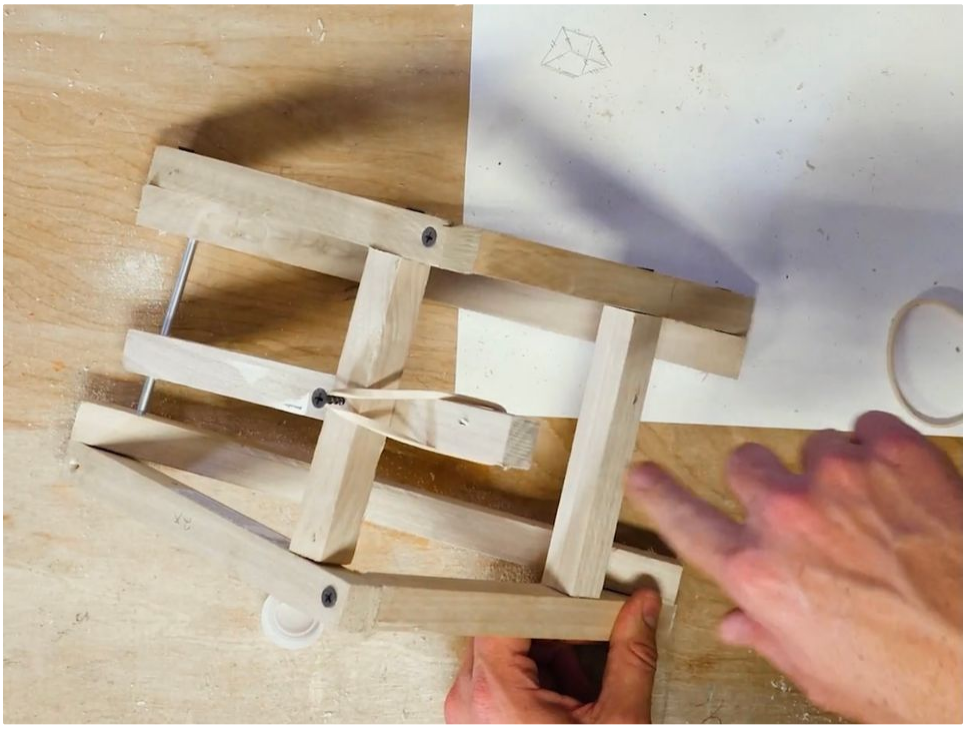
The catapult arm should sit between the other two 5″ brace pieces and be able to move freely between the two. Use this to figure out where the along base pieces, which are now holding the axle in place, you should attach to the catapult frame.



(7) Attach the base pieces to the catapult frame by using the pilot hole and screw technique at each of the four touch points.

(8) Partially screw a screw into the center of the highest brace, so that the screw is perpendicular to the catapult arm at its highest position.

Hook a rubber band around the the catapult arm and the protruding screw.



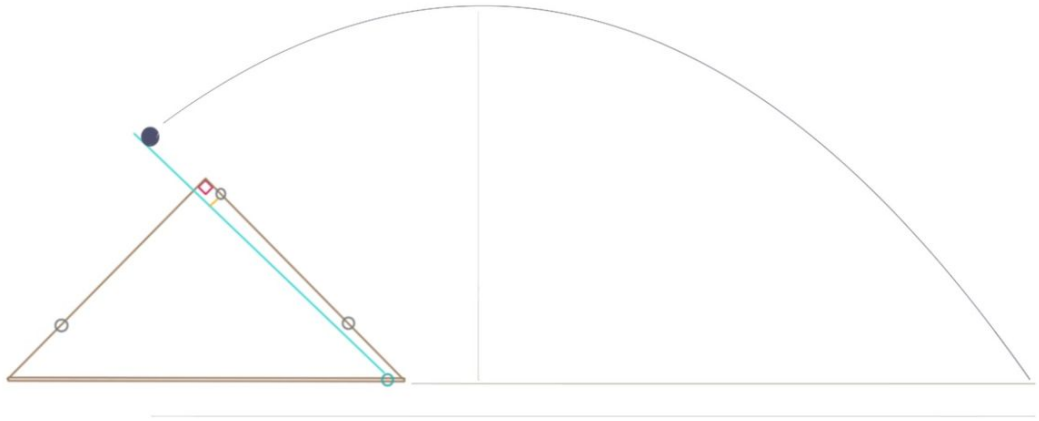
(9) Screw a bottle cap to the end of the catapult arm.

(10) If you're having trouble getting the rubber band to stay hooked around the catapult arm, you can add an additional nail or screw in the side of the arm (which Mark does later in his process).

Testing and Iterating

Congratulations, you have a catapult! Now what?

- To test your catapult, load a projectile into your bottle cap, pull down the arm and then release. You just launched your catapult!
    - Your projectile should follow a curve called a *parabola* in the air. Have someone else launch your catapult while you watch from the side — you should see the projectile follow a parabolic arc.



    - Make a few changes, and see what happens to your parabolic arc. Remember to only change one thing at a time so you can be sure the change in outcome is a result of the thing you changed! Pay attention to the *maximum height* of each parabola (how high your projectile goes) and the *maximum distance* (how far your projectile goes).
        - Try pulling back the catapult arm different amounts before launch. This changes the *force* with which the projectile is launched, which also changes the *velocity* or speed.
        - Try propping up the front or back of your catapult base with blocks. This changes the *launch angle*.
        - Try placing the catapult on a table or a stack of books, or, if it was already on a table, moving it to the floor. This changes the *height* of the launch.
- However you intend to use your catapult, make sure you are meeting your specific design requirements. You can adjust the launch angle, height, and velocity based on your use case.

- Once you're meeting all of your design requirements and you're happy with how your catapult is working, it's time to decorate!
    - You can add any decorations you'd like to help you convey the story of your build.